Statistical Room Acoustics

Sound Absorption

- Most materials absorb sound. A simpler measure of the acoustic properties of materials, the absorption coefficient.
- the absorption coefficient of a given material is the
- absorbed fraction of the incident sound power.
- The absorption coefficient *α* is defined as the ratio of the energies of absorbed and incident sound:

$$\alpha = \frac{\text{absorbed energy}}{\text{incident energy}}$$

- The reflection coefficient *R* on the other hand is the ratio of the sound pressures of reflecting and
- incoming sound:

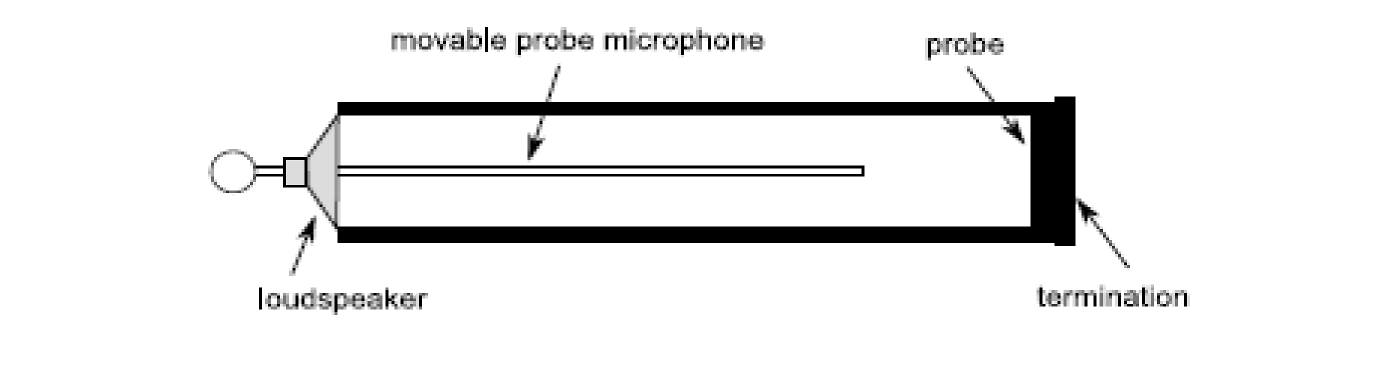
$$R = \frac{\text{sound pressure of reflected wave}}{\text{sound pressure of incident sound wave}}$$

- The absorption coefficient is a real number in the range 0 *. . .* 1. The reflection coefficient is a complex number and describes the amplitude ratio and the phase shift during reflection. Under the assumption that the whole incident energy splits into absorption and reflection, a relation between *α* and *R* can be
- established:

$$\alpha = 1 - |R|^2$$

Measurement of absorption and reflection

- Kundt's tube serves to create a one-dimensional plane wave sound field at discrete frequencies as shown in the figure below.
- A loudspeaker located at one end of the tube generates a sine wave. This wave propagates in the tube to the other end and will be reflected at the hard termination. Thereby the incident and reflected sound wave form an interference pattern with pressure maxima and minima.



- By introducing absorbing material in front of the hard termination.
- In the center of the tube diameter a probe microphone can be moved along the tube axis to detect sound pressure maxima and minima.
- With p_r as sound pressure of the wave reflected at the end of the tube and *pe* as sound pressure of the incident wave one can write:

$$\frac{p_r}{p_e} = \sqrt{1-\alpha}$$

- The sound pressure maxima are formed by constructive interference of incident and reflected wave:

$$p_{\text{max}} = p_e + p_r = p_e(1 + \sqrt{1-\alpha})$$

- The sound pressure minima on the other hand result as destructive interference between incident and reflected wave:

$$p_{\text{min}} = p_e - p_r = p_e(1 - \sqrt{1 - \alpha})$$

With the ratio

$$n = \frac{p_{\text{max}}}{p_{\text{min}}}$$

the absorption coefficient can be calculated as

$$\alpha = 1 - \left(\frac{n-1}{n+1}\right)^2$$

Typical values of the absorption coefficient α for some common materials.

Material	Frequency (Hz) 125	250	500	1000	2000	4000
Brick, bare concrete	0.01	0.02	0.02	0.02	0.03	0.04
Parquet floor on studs	0.16	0.14	0.11	0.08	0.08	0.07
Needle-punch carpet	0.03	0.04	0.06	0.10	0.20	0.35
Window glass	0.35	0.25	0.18	0.12	0.07	0.04
Curtain draped to half its area, 100 mm air space	0.10	0.25	0.55	0.65	0.70	0.70

Equivalent absorption area

- The product of area and absorption coefficient of a surface material is the *equivalent absorption area* of that surface, The equivalent absorption area of a room is

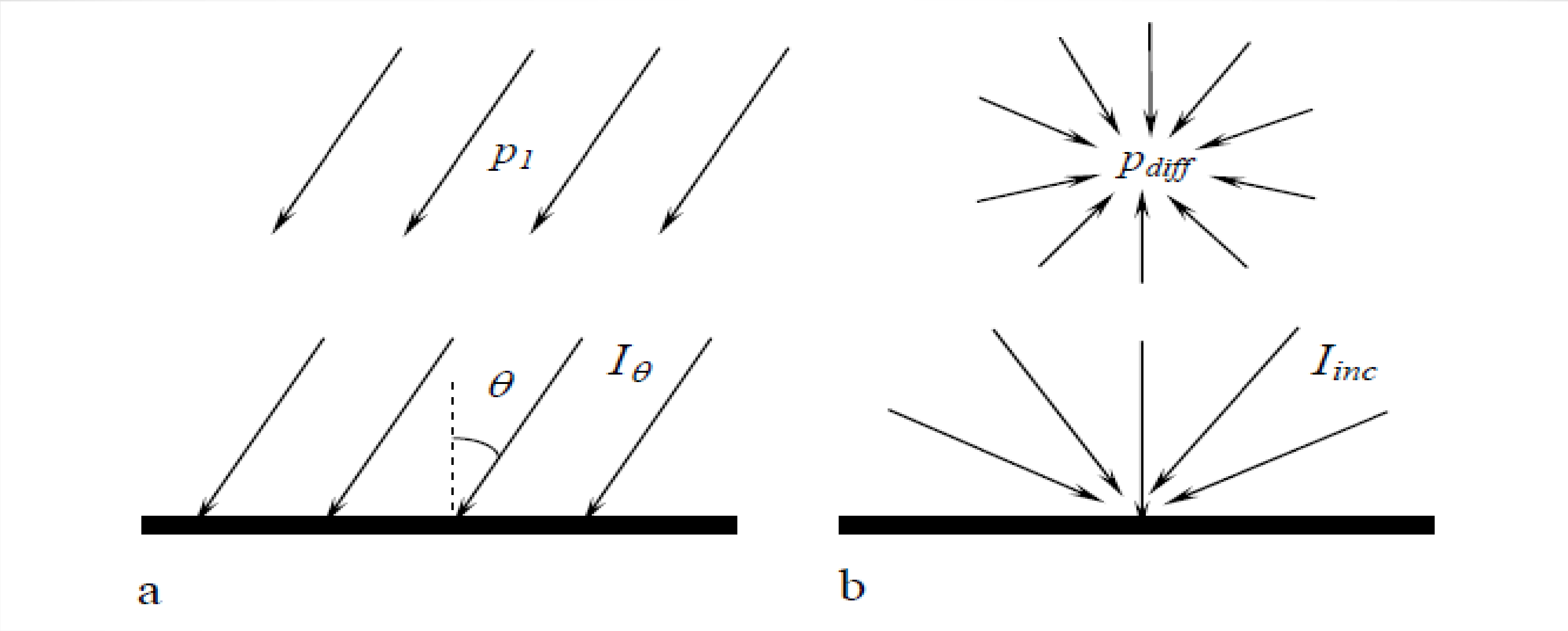
$$A = \sum_i S_i \alpha_i = S_1 \alpha_1 + S_2 \alpha_2 + \quad ..... \quad = S \alpha_m$$

where S is the total surface area of the room and α_m is the *mean absorption coefficient*. The unit of A is m^2. In general, the equivalent absorption area may also include sound absorption due to the air and due to persons or other objects in the room.

The diffuse sound field

The diffuse sound field is defined as a sound field in which:

- The energy density is the same everywhere.
- All directions of sound propagation occur with the same probability.
- In a diffuse sound field the rms sound pressure p_{diff} is the result of sound waves propagating in all directions, and all having the sound intensity I_1.



a: Plane wave incident on a surface. *b: Diffuse incidence on a surface.*

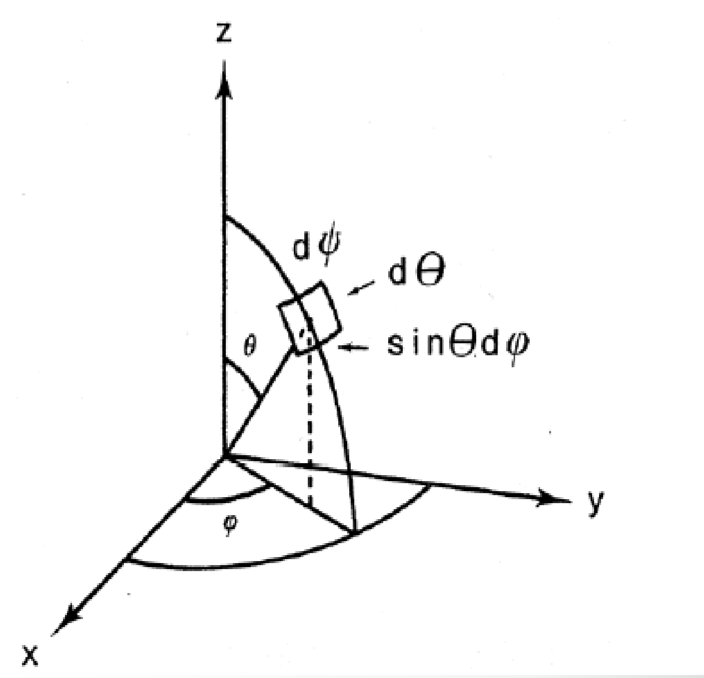
By integration over a sphere with the solid angle ψ = 4π the rms sound pressure in the diffuse sound field is:

$$\tilde{p}_{diff}^2 = \int_{\psi=4\pi} \tilde{I}_1 \cdot \rho\, c \,\mathrm{d}\psi = 4\pi \cdot \tilde{I}_1 \cdot \rho\, c$$

- In the case of a plane wave with the angle of incidence θ relative to the normal of the surface, the incident sound power per unit area on the surface is

$$I_\theta = I_1 \cos\theta = \frac{p_{diff}^2}{4\pi \rho c} \cos\theta$$

The total incident sound power per unit area is found by integration over all angles of incidence covering a half sphere in front of the surface



$$I_{inc} = \int\limits_{\psi=2\pi} I_\theta \, d\psi = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi/2} \frac{p_{diff}^2}{\rho c} \cos\theta \sin\theta \, d\theta \, d\varphi$$

$$= \frac{1}{4\pi} \cdot 2\pi \cdot \frac{p_{diff}^2}{\rho c} \int_0^1 \sin\theta \, d(\sin\theta) = \frac{1}{2} \cdot \frac{p_{diff}^2}{\rho c} \cdot \frac{1}{2}$$

$$I_{inc} = \frac{p_{diff}^2}{4\rho c}$$

It is noted that this is four times less than in the case of a plane wave of normal incidence.